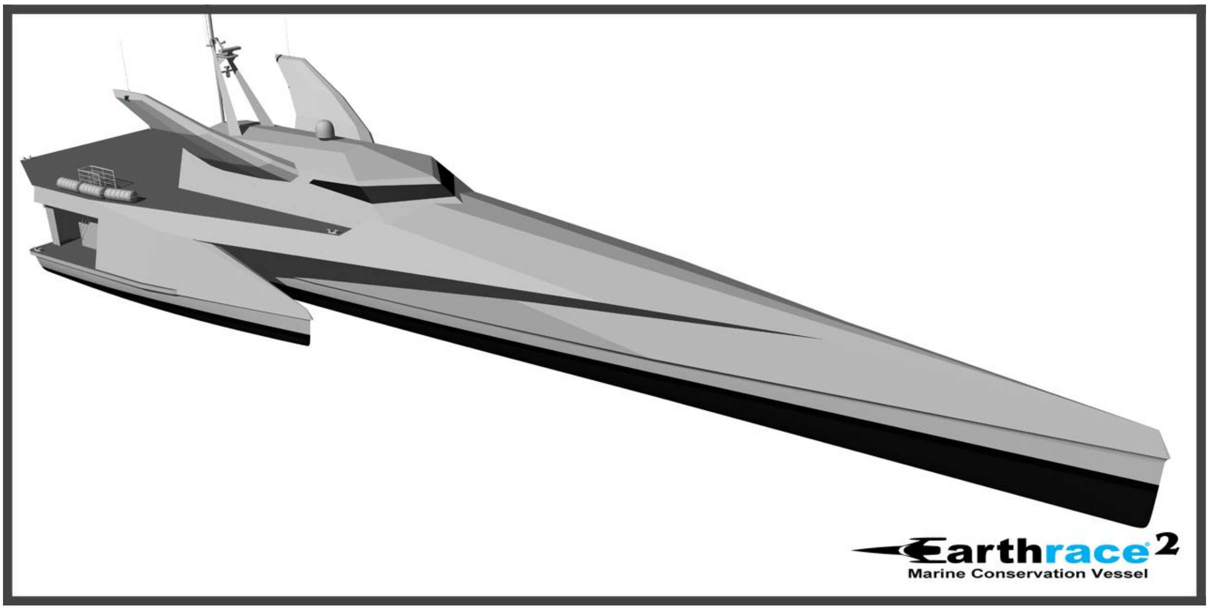
Centre for Engineering and Industrial Design
Engineering Development Project
SCCC701-1700

Using Titanium metal in a marine environment in conjunction with carbon fibre composites

Assessment 4: Project Report



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Abstract

This research is investigating the utilisation of the commercially pure titanium, Cp-Ti, in conjunction with the carbon fibre composites, CFC, in marine environment. This task is to be provided to Earthrace Conservation, which is one of the biggest companies that are conducting voluntary activities around the world. These two metals are to be used in Earthrace-2, which is a developed version of Earthrace-1 vessel. The main goal of this research is to investigate the performance of these two metals when they are being in contact in the maritime environment. Another goal of this research is to outline any breach that might occur of the maritime environment regulations. These achievement of these goals were targeted during all the stages of this project, yet certain maritime regulations were identified and detailed in the regulations section.

This investigation has gone through certain stages in order to be accomplished. The first stage was concerning the collection of relevant data to this project. This was done by gathering information that are related to the utilisation of these two metals in similar conditions. Two examples were provided where these two metals were used in the construction of two different vessels. Certain tests were conducted on the titanium metal in order to identify its mechanical properties. Unfortunately, CFC was not included in these tests because it is not confirmed yet by the manufacturers. These two tests were a practical tensile test and simulated tensile test. The practical test was conducted by using the tensile testing machine in the Tech-gym facility at Wintec Rotokauri Campus, where the simulated test was conducted by using the Solidworks program. Additionally, maximum forces on each component were calculated by using certain formulas. Overall, all obtained values are satisfactory and reasonable.

Introduction

The selection of any metal for a required function is subjected to several factors such as; the desired job, surrounded environment, finance and effort. This was the approach of Earthrace Conservation, which is a company from New Zealand that is investigating a new method to develop Erathrace-1 (ocean-going vessel). The new method is based on combining two different metals, namely, pure titanium and carbon fibre composites, CFC, to be used on the vessel's deck. This company is aiming to consider the marine environment regulations while developing the new Earthrace-2 (a developed model of Earthrace-1), as well as the mechanical performance of these two metals. The main reasons for selecting these two metals are due to the excellent resistance to corrosion, the light weight, which is a great advantage to reduce the fuel consumption and the great withstand to the ocean dynamics such as currents and waves. Additionally, these tow metals are tough enough to resist strong impacts and high temperatures (Agur, 2013; B & Suvidha, n.d.).

Certain mechanical tests were conducted on the pure titanium in order to provide a comprehensive details about the mechanical performance of the titanium metal. This will help Earthrace Company to identify whether or not this metal can perform the desired function. Additionally, there will be a detailed description of how to use the pure titanium metal in conjunction with the CFC in the marine environment, and the expected hazards that need to be considered such as the corrosion threat.

The limitations of this project are revolving around the conduction of the mechanical tests, which were only conducted on the titanium metal. Additionally, the time factor that has affected the progression to investigate the change in performance of the pure titanium metal before and after experiencing the marine environment.

Project Background and literature review

Project background

Any project needs to be investigated and outlined before starting the implementation phase. This process helps to prevent any defect that may arise during the work on this project. Additionally, this procedure is highly recommended by several engineers such as Pirpasha Ujede (Ujede, 2012), and Jaynat R Row (Row, 2011). Some of the advantages of following this procedure are covering all the project's aspects, defining the constructing stages and identifying any potential risks that might affect the progression of the project. This procedure was followed by the Earthrace Company before they started constructing the new ocean-going vessel (Earthrace-2).

This vessel is the developed version of the Earthrace-1, which was manufactured in 2006 (Earthrace World Record, 2008). The aim of producing this new version is to extend the work of Earthrace Company on marine conservation. Several tasks are planned to be achieved by Earthrace-2 such as combating irregular fishing, maintaining the health of the marine environment and contributing in filming a documentary series. It is planned to supply this vessel with the most developed technology that is available for the marine usages. This length of Earthrace-2 will be 59.3m, the beam length will be 12m. The capacity of this vessel is to occupy 14 people as a crew and 14 passengers, with a total of 26 people (Earthrace conservation, n.d.).

Currently, Earthrace Conservation is researching the possibility of using the titanium metal in conjunction with the CFC in the marine environment. The reasons behind this development are quality enhancement, economization and environment protection. Quality enhancement refers to durability, so that the life-service of the vessel's deck is prolonged. In addition, quality development signifies improved corrosion resistance. Achieving the desired quality means less repair and maintenance expenses. Therefore, Earthrace can economise on parts replacement. Using more high quality products and lessening reproduction of consumed parts can contribute to sustainability and hence environment protection. The prime goal of Earthrace Conservation is to meet the marine environment regulations, which were developed by the Ministry of The Environment, Maritime New Zealand, International Standards ISO and the International Maritime Organisation IMO with the new Earthrace-2.

Literature review

The approach of using the combination of titanium metal and carbon fibre composites, CFC, in the marine environment is not a new method. Wally Yachts is a Monaco company that used these two metals in their design when they manufactured the Dark Shadow boat. This unique yacht was designed to offer better services in terms of luxury needs and safety, better corrosion resistance due to the materials used which prevent this kind of impact in marine environment, as well as higher speed while sailing due to the light weight of the structure of the boat (Foster + Partners, 2003). The following figure shows the deck of the Dark Shadow boat were the titanium metal and CFC were used.

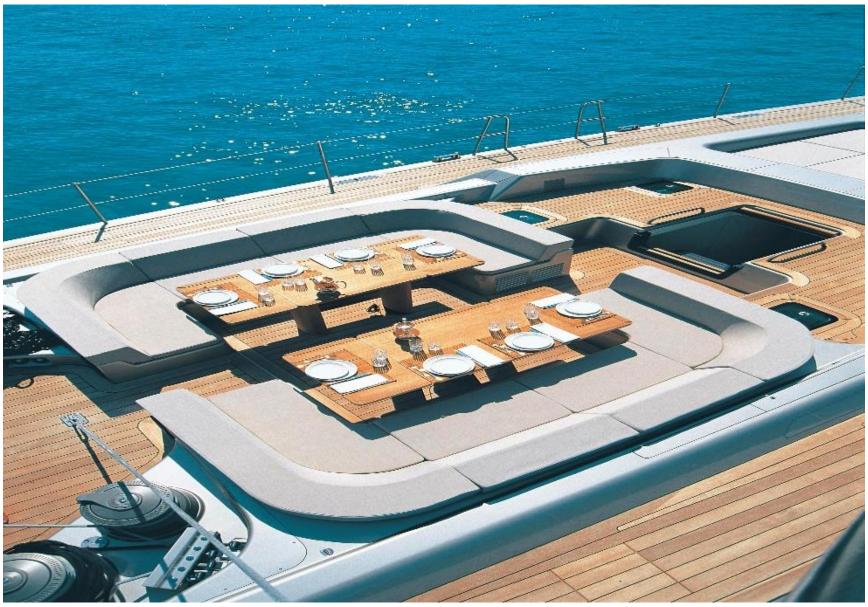


Figure 1. Dark Shadow boat (Foster + Partners, 2003)

Titanium metal was not only consumed in marine environment. Some countries such as Japan are using this metal for several applications. The following figure shows certain utilizations of the titanium metal in Japan during the last century.

Table 1. Utilization of titanium metal in Japan during last century (Matsuo, 2002)

Period	Market section and Technical trend	Typical applications
Mid/late 1950s	· Advent of industrial production · Beginning of market development	Chemical industries (plant piping, heat exchangers)
1960s	· High grade corrosion resistant material	Lining of reaction vessels and towers, heat exchanger tubes, piping
1970s	· Electrodes for soda industry · Air pollution problems	Electrodes, electrolytic cells Flue gas desulfurization plants
Late 1970s to early 1980s	· Increase of power demands · Seawater desalination plants	Condensers for power plants Electrothermal tubes of seawater desalination facilities
Mid 1980s to present	· Building, marine and civil construction · Daily and leisure commodities · Cars, motorcycles	Roof lining of covered athletic fields, etc., building exterior panels Table ware, eyeglass frames, golf clubs, plate heat exchangers Auto engine parts, mufflers

Mountford and Scaturro (n.d.) in their research stated that titanium metal was proven over many years to be one of the most efficient metals that can prevent the corrosion impact in seawater, as well as having a great advantages in weight saving and high strength due to its low density. Additionally, low maintenance required in failing accidents because of the durability and elimination of titanium metal in marine environment (P. 1).

(Murphy, 2013) has mentioned some of the advantages of using the carbon fibre composites in vessels' decks. Some of the comments that were provided are carbon fibre composites are having stiffer modulus of elasticity in comparison to other metals. This gives it the advantage to be highly recommended to be used in the marine environment because it does not corrode easily. Certain criticisms were provided in the same article regarding the manufacturing processes for this composites as they need to be manufactured carefully, as well as the high cost when recycling (Para. 10).

Brodrene AA Company is known as the world leader in manufacturing the new type of fast ferries that are made of carbon fibre composites. This company has stated some of advantages of using these composites when constructing their ocean-going vessels, which are as follows:

- High strength and low weight
- Flexibility of these composites as they can be used in several applications
- More economical in fuel consumption
- Environmental friendly
- Reduction of external maintenance, where it can be reduced by 50%
- High efficiency of products that made of carbon fibre composites where they can be operated for a long time (Brodrene AA, n.d.a).

Brodrene AA has provided relevant information about how carbon fibre composites have become in more demand in the Norwegian market. The following chart was taken from their site, which illustrates the high consumption of these composites in comparison to other materials.

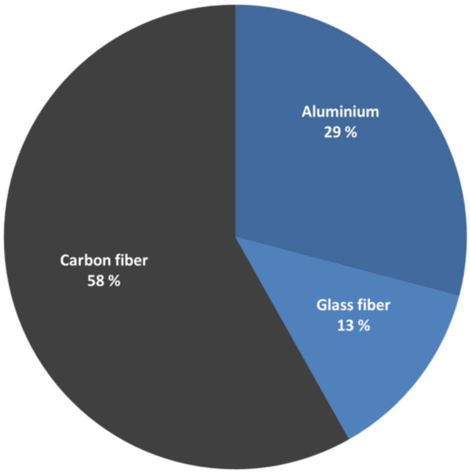


Figure 2. Consumption of carbon fibre in Norwegian markets (Brodrene AA, n.d.)

(Houser, 2011) has mentioned in this report (Ti review for seawater applications) that the speed of wend in the marine environment plays an important factor that can impact the function of the titanium part. During his test, he has highlighted the importance of concerning the bio-fouling that can occur in several applications such as: condensers, exchangers and piping. As Robert said, one test was carried-out for a year in the marine environment that was at a speed of 9.1 (m/sec) on a titanium part. The results were positive due to no sign of corrosion or bio-fouling on the titanium part. Additionally, the pure titanium showed an erosion resistance at velocities up to 5.5 (m/sec) with silt/laden seawater, and above 30.5 (m/sec) in silt-free seawater (P. 2-3).

Another company from Monaco have followed the same approach in making their sport yacht which is called Niniette. This company is called Palmer Johnson whom are experienced in constructing luxury vessels. The idea comes from the intention of producing stronger boats that can perform excellent in marine environment and withstand its impact. However, their new boat which was produced in collaboration with the Bugatti Company consisted of both titanium metal and carbon fibre composites on this yacht's hull and deck (Keeshin, 2016).

The following figure is a photo that was taken of the Niniette boat.

Figure 3. Niniette sport boat (The drive, n.d.)

Corrosion threat

It is important to understand the threat on metals if they are being used in the marine environment. The main hazard that can attack these metals is the corrosion. This impact is due to the chemical reactions between the surrounding environment and the utilised metals. The severity of this corrosion depends on the type of materials used, and the surrounding environment. For example, some materials can be easily corroded such as pure iron; zinc and magnesium, whereas other materials such as gold; platinum and silver are corrosion-resistant. These materials which show better resistance to corrosion are called Noble metals. They were given this name due to the fact that they are less affected by the corrosion phenomena, as well as due to being the only elements that can be found in nature in their pure form (Bell , 2017). The environment is playing an effective role in this process. For example, wet environment is the most preferred surrounding to corrosion to develop rather than dry environment due to the abundancy of water drops in the air.

Corrosion is the reverse processes of a manufactured metal returning to the natural state, where they were oxidised (Escobar & Cantu, 2014, Para. 1). It starts when three main conditions are combined together. These three standards are as follows:

1- The metal itself, which is the main examined element or the object that is going to experience the chemical reactions (oxidation and reduction)
2- Oxygen, which is already exist in the atmosphere
3- An electrolyte, which is a liquid that contains ions, for example, metal ions (Para, 3).

The oxidation reduction (corrosion) process is, as its name suggests, involves two chemical reactions, namely, oxidation and reduction. The oxidation reaction takes place at the anodic electrode, however, the reduction reaction occurs at the cathodic electrode. The oxidation and reduction reactions happen simultaneously, that is to say, the rate of each reaction is the same as the other. This is because as the anodic electrode releases electrons, the cathodic electrode consumes these electrons (Davis, 2000, p. 24). Therefore, the weight loss does occur at the anodic electrode.

Corrosion can be examined and tested by three main methods. These methods are explained below:

1- Service history, which is the most reliable and available method due to its simplicity, as it is based on monitoring the metal over a specific period of time. The only issue with this method is that the data obtained can be inaccurate due to the difficulty to predict the real conditions that have been experienced by the metal.
2- Field performance, which is similar to the previous method but entails extra technique. The performance variable of the examined metal can be extrapolated in order to approximate the product's performance after a certain period of time
3- Accelerated corrosion testing method, which is the most common method due to the accurate results that can be obtained in a shorter period of time (Corrosion Testing, n.d.).

Having two dissimilar metals in contact in a marine environment will result in either simple corrosion or galvanic corrosion. Simple corrosion can be easily combated by using the metal oxide coating, which helps to prevent oxygen from reaching the metal's surface. This form of corrosion is not the real threat because it takes a long period of time to weaken the metal. The real threat is the galvanic corrosion, as it can be developed easily when oxygen and moisture are present. The electrochemical potential determines which metal is to be either cathode or anode. In other words, the less electronegative of the two dissimilar metals will act as an anode, whereas the more electronegative of the two will act as a cathode. Additionally, as the difference of electronegativity between any two metals increases, the corrosion development will be hastened (Sherman, 2015). Due to the small gap between the pure titanium and carbon fibre composites in terms of their electrochemical potentials, they can be safely coupled in the marine environment. However, to decelerate the corrosion process even further, one ought to realise the significance of separating the two metals using an electrical insulating material (Yari, 2017). Several ways can be used to quantify the corrosion pit. The direct method starts with cleaning the surface of the inspected sample, normally by sand and blasted grit. Then, the sample is to be transferred to the laboratory to measure the pit depth. Indirect methods are more preferred in the field test where the attacked part can be easily inspected by using the several methods such as X-ray radiography, 3D-optical microscope, etc. (Gelz, Yasir, Mori, Meyer, & Wieser, n.d.).

Marine environment regulations

Marine environment regulations are outlined in this section, so that all processes and materials utilised in this investigation are standardised and in accordance with the maritime codes. Maritime New Zealand is a Crown entity that was established in 1993 to take the responsibility of securing, protecting and monitoring the safety of the coastal and inland waterways (Maritime New Zealand, n.d.). This governmental sector has decided upon several standards in order to maintain the safety of the marine environment. For example, the regulations for maritime transportation system were addressed in part19 in the maritime rules. This standard regulates certain operations that are maritime transportation-related. Some of these requirements are: Any operator must hold a maritime license in accordance with the training and examination section, which is Part 35 in the same regulations (P. 4). This rule applies to the new Earthrace-2, which will be designed for voluntary transportation purposes in the coastal waters.

The same organisation (i.e. Maritime New Zealand) has stated several specifications for different ships' dimensions and their capacities. The standards that must be followed to design and construct the Earthrace-2 have not been determined yet. However, Part 40G can be used as the basis to initiate the basic standards for the Earthrace-2. Part 40G, emphasises the importance of inspecting and ensuring the safety of the constructed vessel, crew and the environment. It is obvious that any defects in the new Earthrace-2 can be conducive to harmful effects on the crew, the vessel itself, or the marine environment. This matter is addressed by the Maritime New Zealand under the sections: Health, safety and welfare of ships; Personal and General marine protection. The International Maritime Organisation IMO has stated several standards in order to maintain the safety of the sea. These standards applies for the Earthrace-2 due to the working nature of this vessel in the sea water. Some of these standards are: Maritime Safety Committee MSC, which consists of 12 sessions and deals with all matters that are related to the maritime environment; and the Facilitation Committee FAL, which deals with the legal obligations that are required by the vessel's crew and passengers (International Maritime Organisation, n.d.).

Methodology

This project has gone through five main stages in order to define the possibility of using the commercially pure titanium metal and carbon fibre composites in the marine environment. The first stage was about understanding the project and identifying any potential hazards that might occur under any circumstances. The second phase was about collecting data and gathering any relevant information about these two metals, also any previous utilisation of these two metals in similar conditions. The third stage was about defining the required equipment and tools in order to construct certain mechanical tests on the titanium metal. This procedure has been an advantage for this project, which has helped in defining the mechanical properties of the titanium metal. This process is further explained in the designing and testing sub-task where the two testing methods are detailed. The fourth stage was concerning the formulas that were used to construct the theoretical calculations. The final stage was about confirming the data collected from the theoretical and practical tests with the academic supervisor. More information about the five main stages are further explained in the following sub-tasks.

Issues identification

At the start of this project, certain factors were taken into consideration due to their importance when using the pure titanium metal and the carbon fibre composites in the same working field. Some of these factors are related to the marine law, others are related to the financial factor or their mechanical properties. The main purpose of following this procedure is to identify any potential hazards that might occur, providing suitable solutions for any situation and to overcome the issue before it comes to action. The main factors that were considered are listed below:

- Equipment and materials' cost
- Corrosion threat when having these two metals in contact
- Limited information about some mechanical properties that are related to these two metals
- Calculation difficulties especially when defining the maximum forces that can be withstood by each metal
- Designing testing parts and constructing the mechanical tests

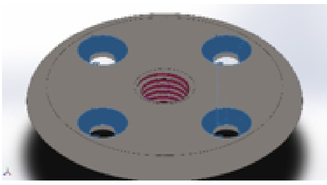
Data collection

Titanium metal and carbon fibre composites CFC were investigated in detail in order to define any relevant information that could help in this project. Basic information such as the Ultimate Tensile Stress UTS, Yield stress YS and the Modulus of Elasticity E for the CFC and the pure titanium Cp-Ti were taken from certain online sources such as the Engineering Toolbox web-site. These values were utilised in the calculation method in order to identify the maximum forces that can be loaded on each metal. This procedure has helped in defining the breaking load for the titanium metal. Additionally, the same information was collected for other metals that were used in the practical tests. As a part of this stage, the required formulas were prepared in order to be used in the theoretical calculation. Several sources were utilised to collect the data for this project. Some of these sources are books such as the Machinery's Handbook, others were online sources such as (Ultimate tensile strength, n.d.), (Tensile Stress Area of a Bolt, 2013).

Designing and testing

The designing stage has gone through two main phases, the Solidworks program and practical designing. The Solidworks designing was the initial stage of this method. The parts required to construct the tensile test were drawn by using this program, then a simulated tensile test was applied on them. Unfortunately, the Solidworks program could not recognise the whole components, therefore only the titanium sample has been subjected to this test. The following tables show the load and fixtures for the titanium sample, also the titanium properties when the tensile test was conducted by the Solidworks.

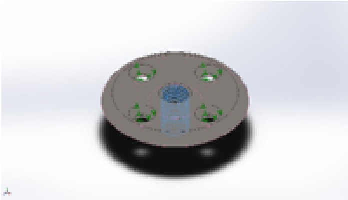
Table 2: Fixture points during the simulated test

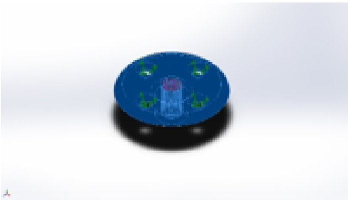
Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 4 face(s) **Type:** Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	0.0843129	-20000.5	0.429436	20000.5
Reaction Moment(N.m)	0	0	0	0

Table 3: Prosperities of the titanium sample

Load name	Load Image	Load Details
Force-2		**Entities:** 1 face(s) **Reference:** Face< 1 > **Type:** Apply force **Values:** ---, ---, 20000 N

Model Reference	Properties	Components
	Name: **Commercially Pure CP-Ti UNS R50700 Grade 4 (SS)** Model type: **Linear Elastic Isotropic** Default failure criterion: **Unknown** Yield strength: **5e+008 N/m^2** Tensile strength: **5.5e+008 N/m^2** Elastic modulus: **1.05e+011 N/m^2** Poisson's ratio: **0.37** Mass density: **4510 kg/m^3** Shear modulus: **4.5e+010 N/m^2** Thermal expansion coefficient: **9e-006 /Kelvin**	**SolidBody 1(Cut-Sweep1)(testing sample)**
Curve Data:N/A		

In regards to the practical test, certain tools were required before starting. These tools are listed below:

- Tapping and threading tools with different sizes
- Titanium samples (Cp-Ti)
- High tensile stainless steel bolts (A2-70 the)
- Eye bolts with different sizes (14 & 16 mm)
- 316L Stainless Steel material (to be used as a tensile grip)
- Steel material sample (to be used as a holder for threading processes)
- Bow shackles (to connect the eye bolt to the machine's base)

Figure 4: Tensile testing machine

Figure 5: All components during the tensile test

All this equipment was provided by the academic supervisor Dr Paul Ewart. The practical test started with tapping the titanium samples by using the tapping tool. This was done manually by using the Tech-facility at Wintec's Rotokauri Campus. First stage was started with drilling the steel material sample to fix the titanium part while threading. Next, the titanium part was fixed on the steel sample by using a stainless steel 8mm bolts and nuts. Two different sizes were used for the middle hollow of the titanium metal. These sizes are 16mm and 14mm. The diameter of the middle hollow for the titanium parts were adjusted with 12mm and 14mm drilling tools. The idea is to use the 12mm drilling tool with the 14mm tapping tool, and the 14mm drilling tool with the 16mm threading tool. This procedure has provided the required threading dimensions and the required tension area when the 14mm and 16mm eye bolts were utilised in the tensile test.

Designing the tensile grip was the critical part in the designing stage. Several ideas were negotiated with the academic supervisor in order to find the most suitable design. As a result, the final design of the tensile grip was agreed and confirmed. This was done by taking certain criteria into consideration such as the ultimate tensile strength of the grip's material, and the shape of the tensile grip which had to be done based on titanium sample and the bolts sizes.

After having all the components prepared, the practical tensile test was constructed with the supervision of the academic supervisor Dr Paul Ewart. The outcomes of this test were compared to the calculated results and the simulated test which was done by the Solidworks program. Error percentages between all results were calculated and defined.

Mathematical processes

The following formulas were retrieved from (Ultimate tensile strength, n.d.) (Frustum of a Right Circular Cone, n.d.), (Tensile Stress Area of a Bolt, 2013) respectively.

Finding the maximum forces ($\boldsymbol{F}$)

$$Force\ (Newton) = Stress\ (N/m^2, Psi) * Area\ (m^2) \quad \text{... (Equation 1)}$$

Inclined area calculation at the 4 bolt sections on the titanium metal

$$A_l = \frac{1}{2}(2\pi R + 2\pi r)L \quad \text{... (Equation 2)}$$

∴ This is illustrated at the bottom of this page

Finding the stress area for the bolt ($\boldsymbol{mm^2}$)

$$\boldsymbol{A_t = 0.7854\left(D - \frac{0.9743}{n}\right)^2} \quad \text{... (Equation 3)}$$

$$\therefore D\ is\ the\ bolt\ diameter, n\ is\ the\ number\ of\ pitches\ per\ mm$$

The following shapes illustrate the principle of using the frustum cone's formula when finding the area that is subjected to a compression force by the bolt. Only the side areas were calculated where the top and bottom areas of the cone were excluded from the area value.

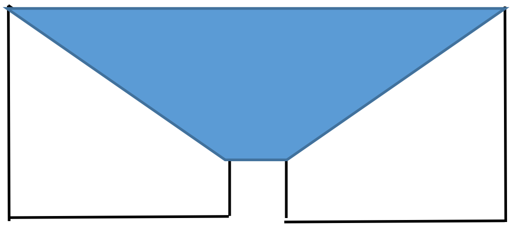


Figure 7: Inclined part of the titanium sample

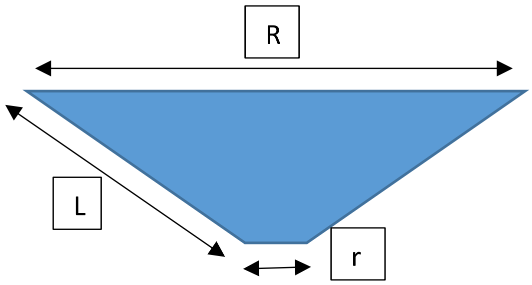


Figure 6: Dimensions of the surface area

Data confirmation

The collected data from both tests, Solidworks and practical tests, also the calculated values were recorded, then error percentages were defined. These values were revised several times in order to be confirmed. As an advantage of the theoretical part in the calculation processes, the maximum forces that can be applied on any material can be easily calculated in further researches by following the same steps. Only area and ultimate tensile stress values must be changed when calculating the maximum forces that can be applied on any material used. After defining maximum forces on all areas, the lowest force needs to be agreed as the maximum force that can be applied on the system. Exceeding this force will lead to a failure on the system.

Results

Practical test result

The practical test was conducted five times on five different samples of the commercially pure titanium samples. All these samples have passed the applied forces with no failures. The applied forces were restricted to 20KN, and at a speed of 5mm/min. The following figure shows the obtained average value of the practical tests. It can be seen that the system continued on the linear portion, which means that there were no elongation on the system, nor failure at any part. This means the system has the capacity to withstand 20KN when experiencing the same speed of external forces.

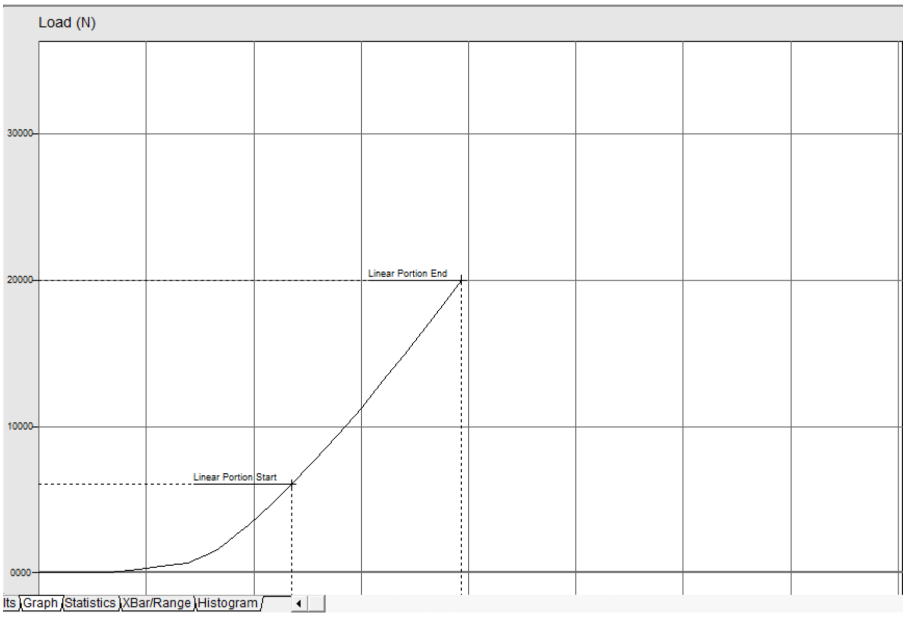


Figure 8: Force vs time during practical test

Results from the first until the fifth attempts were recorded during the adjustment of the machine, which are not relevant to the results of this test.

	Sample...	Direction	Preload/stress	Preload/stress Speed	Speed	Diameter	Area	Limit	Timestamp	User	Tensile Strength
1	True	Tension	0.050000 kN	5.0000 mm/min	5.0000 ...	13.500 mm	143.14 ...	20.000 kN	1/11/2017 ...		
2	True	Tension	0.050000 kN	5.0000 mm/min	5.0000 ...	13.500 mm	143.14 ...	20.000 kN	1/11/2017 ...		0.0079951 MPa
3	True	Tension	0.050000 kN	5.0000 mm/min	5.0000 ...	13.500 mm	143.14 ...	20.000 kN	1/11/2017 ...		0.015990 MPa
4	True	Tension	0.050000 kN	5.0000 mm/min	5.0000 ...	13.500 mm	143.14 ...	20.000 kN	1/11/2017 ...		0.00000 MPa
5	True	Tension	0.050000 kN	5.0000 mm/min	5.0000 ...	13.500 mm	143.14 ...	20.000 kN	1/11/2017 ...		0.023783 MPa
6	True	Tension	0.050000 kN	5.0000 mm/min	5.0000 ...	13.500 mm	143.14 ...	20.000 kN	1/11/2017 ...		139.87 MPa
7	True	Tension	0.050000 kN	5.0000 mm/min	5.0000 ...	13.500 mm	143.14 ...	20.000 kN	1/11/2017 ...		139.85 MPa
8	True	Tension	0.050000 kN	5.0000 mm/min	5.0000 ...	13.500 mm	143.14 ...	20.000 kN	1/11/2017 ...		139.97 MPa
9	True	Tension	0.050000 kN	5.0000 mm/min	5.0000 ...	11.500 mm	103.87 ...	20.000 kN	1/11/2017 ...		192.75 MPa
10	True	Tension	0.050000 kN	5.0000 mm/min	5.0000 ...	13.500 mm	143.14 ...	20.000 kN	1/11/2017 ...		142.76 MPa

Figure 9: All results of practical test

Mathematical processes

The following graph shows the ultimate tensile stress for the commercially pure titanium Cp-Ti in comparison with the titanium alloy (Ti64). This test was conducted by then manufacturers of the titanium samples. The main reason for including this result in here is that to confirm the exact UTS value for this metal.

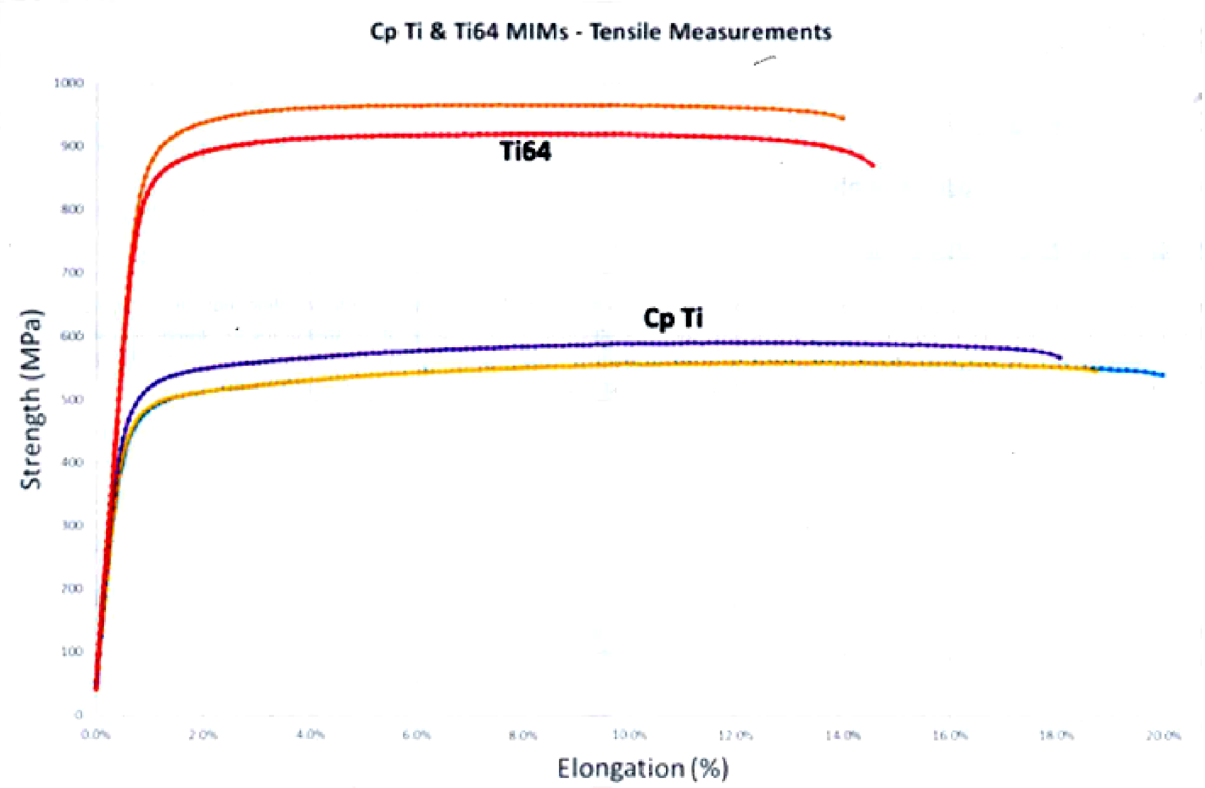


Figure 10: UTS, YS and elongation values from manufacturers

Based on this test, the following values were obtained for the Cp-Ti.

Table 4: Values of the Cp-Ti from the graph

Cp-Ti	Value
UTS (MPa)	560-590
YS (MPa)	450-490
Elongation (%)	18-20%

Calculating the stress areas for the 8mm bolt, 16 and 14mm eyebolts which were used during the practical test by using Equation 3

$$A_{8mm\ bolt} = 0.7854\left(8 - \frac{0.9743}{1}\right)^2$$

$$A_{8mm\ bolt} = 38.8mm^2$$

$$A_{14mm\ eyebolt} = 0.7854\left(14 - \frac{0.9743}{2}\right)^2$$

$$A_{14mm\ eyebolt} = 140mm^2$$

$$A_{16mm\ eyebolt} = 0.7854\left(16 - \frac{0.9743}{2}\right)^2$$

$$A_{16mm\ eyebolt} = 185.07mm^2$$

$$A_{inclined\ part\ for\ titanium} = \Big(\big((2\pi * 15) + (2\pi * 8)\big) * 8.9\Big)$$

$$A_{inclined\ part\ for\ titanium} = 1286.17mm^2$$

$$A_{titanium\ pulling\ section} = 0.7854\left(16 - \frac{0.9743}{2}\right)^2$$

$$A_{titanium\ pulling\ section} = 140mm^2$$

Table 5: Ultimate tensile stresses for the materials utilised

Material	Ultimate tensile strength (UTS), MPa
Pure titanium (Cp-Ti)	560-590
316L Stainless Steel	620-795
A2-70 bolt	700

The above values were utilised to determine the maximum forces on each component by using Equation-1 in the mathematical processes section.

$$\max F_{titanium\ pulling\ section} = 575MPa * 140mm^2 = 80.5KN$$

$$\max F_{titanium\ inclined\ part} = 575MPa * (1286.17mm^2) = 739.55KN$$

$$\max F_{A2-70\ bolts} = 700Mpa * (4 * 38.8mm^2) = 108.64KN$$

$$\max F_{316L\ Stainless\ steel\ grip} = 707.5MPa * (4 * 38.8mm^2) = 109.804KN$$

$$\text{Alawble } F\ \ for\ 16mm\ eyebolt = 700KG * 9.81 = 6.867KN$$

$$\text{Alawble } F\ \ for\ 14mm\ eyebolt = 500KG * 9.81 = 4.905KN$$

Simulated test

The following results were obtained from the simulated tensile test by using the Solidworks program. The applied force is similar to the force in the practical test, which is 20KN.

Table 6: Reactive force

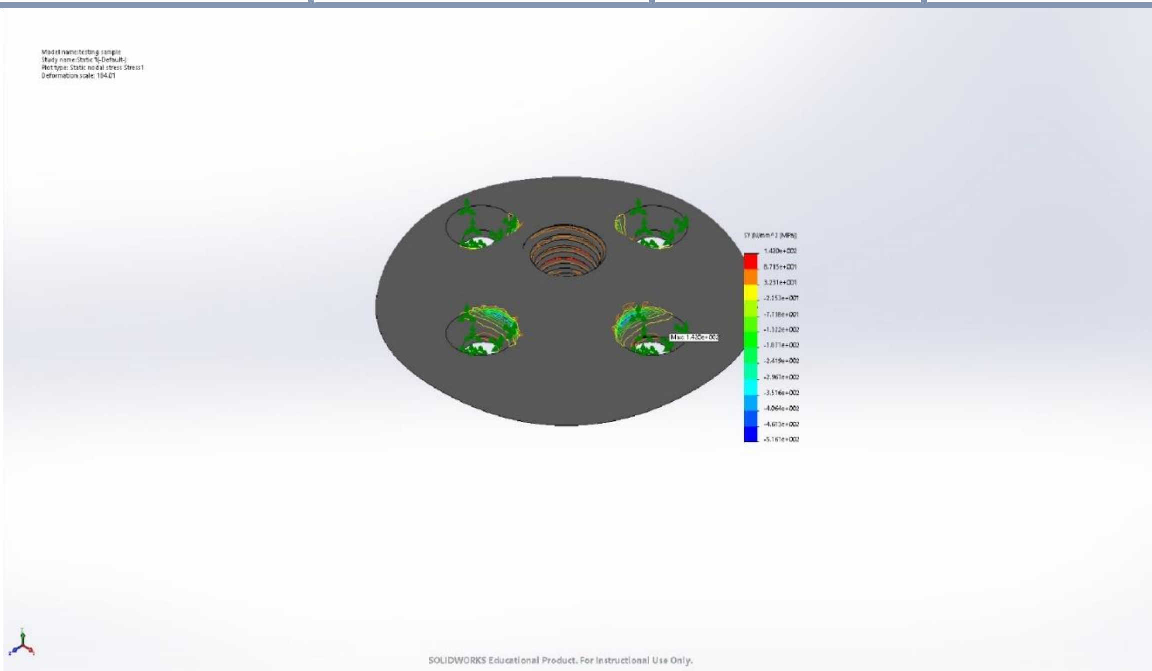
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	0.0843129	-20000.5	0.429436	20000.5

Table 7: Reactive moment

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

Table 8: Stress area during the tensile test

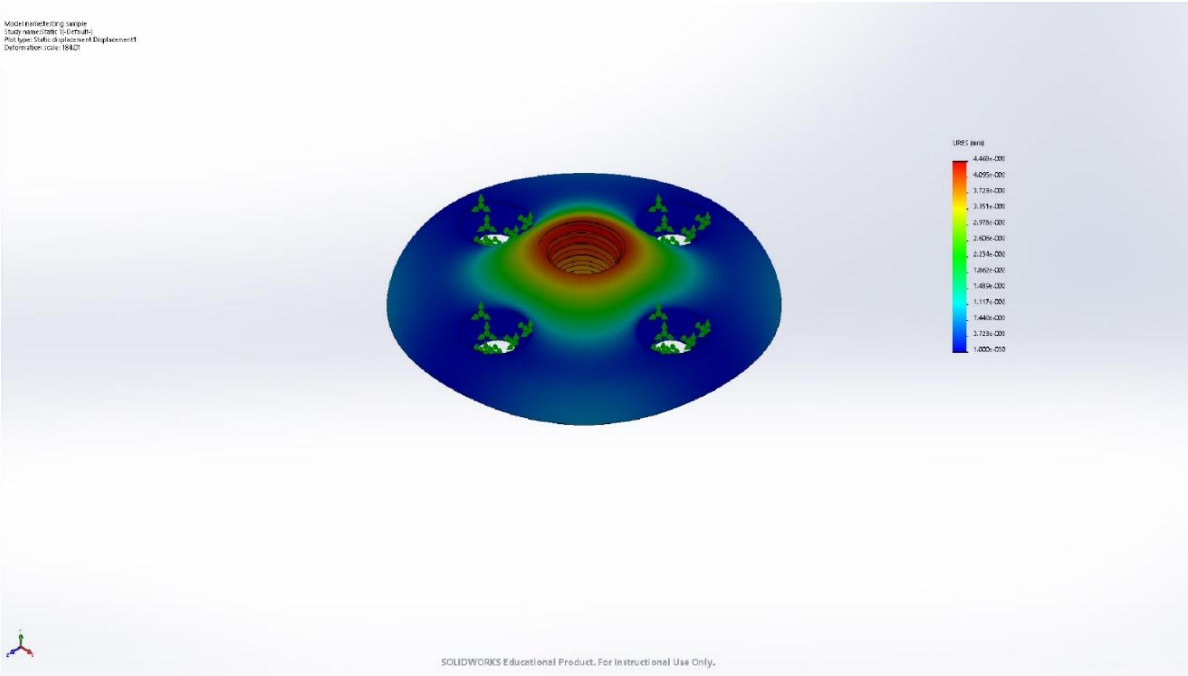
Name	Type	Min	Max
Stress1	SY: Y Normal Stress	-516.123 N/mm^2 (MPa) Node: 86533	141.998 N/mm^2 (MPa) Node: 86016



testing sample-Static 1-Stress-Stress1

Table 9: Displacement locations in the specimen

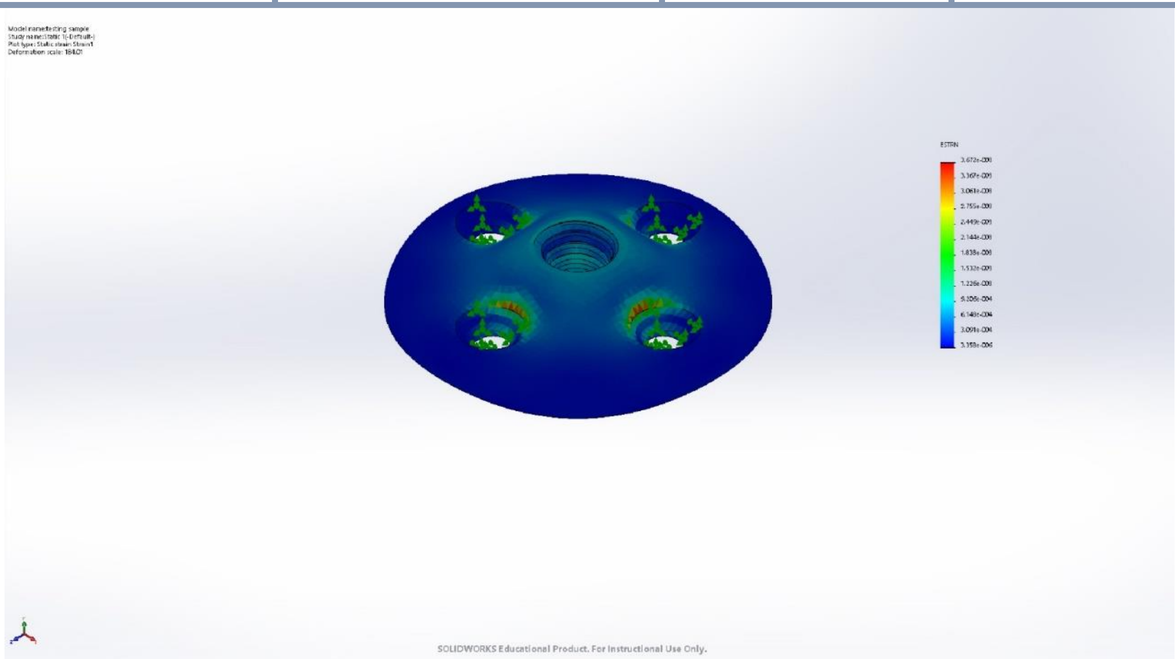
Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0 mm Node: 1871	0.0446762 mm Node: 2860



testing sample-Static 1-Displacement-Displacement1

Table 10: Strain areas in the specimen

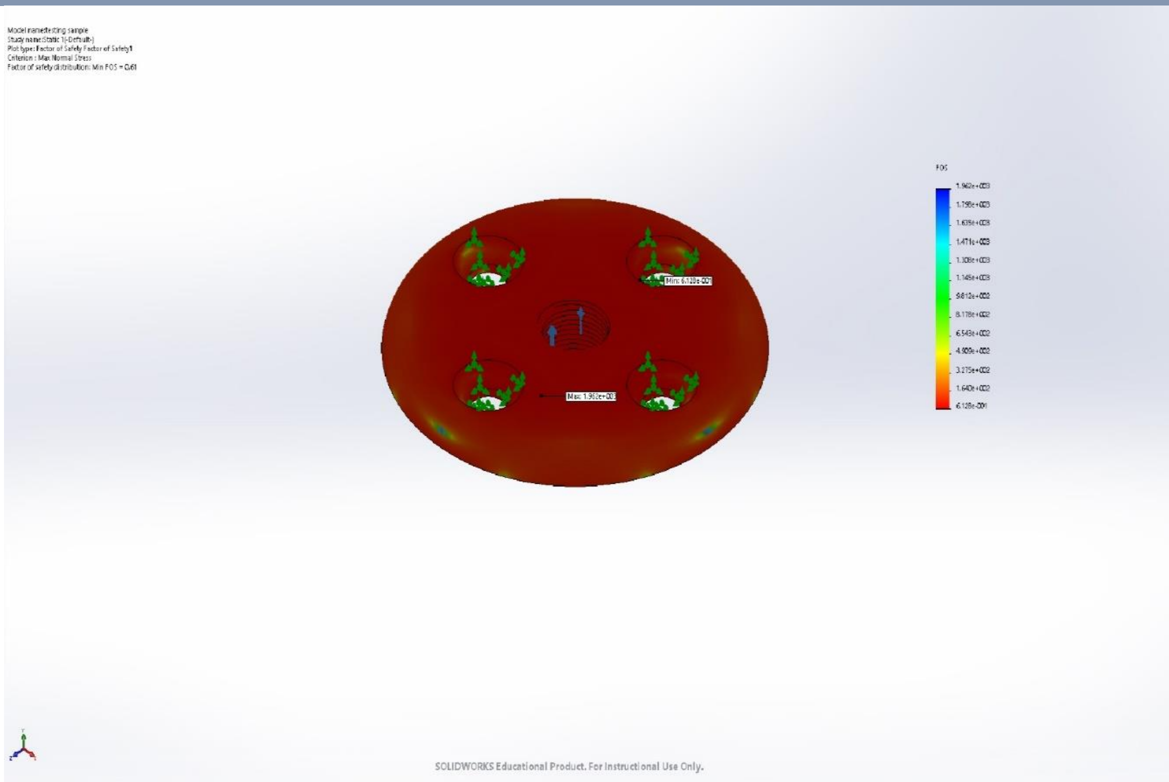
Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	3.35839e-006 Element: 40264	0.0036723 Element: 44812



testing sample-Static 1-Strain-Strain1

Table 11: Maximum and minimum factors of safety

Name	Type	Min	Max
Factor of Safety1	Max Normal Stress	0.612808 Node: 86533	1961.79 Node: 6190



testing sample-Static 1-Factor of Safety-Factor of Safety1

Discussion

The practical test was successfully completed with no deformation or failure in any part of the loaded components. This means that the whole components are capable to withstand similar force in the working environment. However, this force was conducted only once on each titanium sample. The repetition of this test over a long time may provide other results. The eye bolts, 14 and 16mm, were close to fail but they have withstood the applied forces. This means that the maximum forces provided on their description are based on the safe working conditions before being deformed. This procedure is followed by manufacturers to avoid sudden accidents that can occur when exceeding the maximum loads on the product.
The applied force on the practical test is 20 KN. The reason for applying this amount as a tensile load is to stay under the safe working force. This is due to the limitation of the tensile testing machine, where its maximum capacity is 30KN. The data recorded from the practical test were compared to the results from the simulated test. In the practical test, the average UTS is around 140MPa. This result is close enough to the result from the simulated test. Titanium metal has experienced the same force, 20KN, by using the Solidworks program. This is to observe the differences between the practical and simulated test. However, the small difference between these two tests in terms of the UTS makes them both acceptable.

The maximum forces at any part of this system had to be calculated by using the formulas on the methodology section. These formulas were utilised in respect to the shape of the investigated section. For example, the areas of inclined surfaces on the titanium metal were calculated by using the second formula in the calculation processes section. The outcomes of this method show that the maximum force that can be applied on the system when using the 14mm eyebolt is 4.9KN. However, this force can be increased when using the 16mm eyebolt, where it can reach 6.8KN.

The results of the titanium metal shows that this metal has the ability to withstand up to 80.5KN. This force is the maximum force that can be applied on this metal without being deformed. Additionally, this amount means that the weakest point on the titanium sample is in the middle section, specifically in the threads at the pulling area. The recorded results of the titanium metal are satisfactory due to the ability to resist high forces, and due to the excellent performance against external implications.

Conclusion and Recommendation

The outcomes of this research has proven the prescription of the titanium metal in terms of withstanding external forces. This is due to the high UTS of the Cp-Ti in comparison to other metals. According to the practical and simulated tests, this metal has the capacity to withstand tensile forces up to 20KN, where the breaking load should be at 80.5KN at the threads in the middle section of the titanium sample. This metal can be safely coupled to the CFC in the marine environment due to the small values of their electrochemical potentials. Due to the small gap between their electrochemical potential, the risk of corrosion is low. However, to decelerate the corrosion process even further, one ought to realise the significance of separating the two metals using an electrical insulating material.

The conduction of practical and simulated tests were limited to the titanium metal. This is because the exact CFC is not confirmed yet by the manufacturers. However, these composites were detailed in general in previous sections. Other factors were limiting the progression of this project such as lacking the ability of using the Tech-gym facility, which has resulted in manufacturing one part of the practical test's component in external machinery workshop. Additionally, the limited sources of previous utilisation of the Cp-Ti and CFC in conjunction in marine environment were a challenging task that has required extra effort. However, the following are certain recommendations that can be followed in further researches in order to provide better results.

- Conducting the same tests on the CFC when it is confirmed by the manufacturers.
- Using a tensile testing machine that has higher capacity of force.
- Exposing both metals to a simulated marine environment, then observing the differences, also conducting several mechanical tests on different sizes of the samples.

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Glossary

Marine environment: "The oceans, seas bays estuaries and other major water bodies" (Definitions.net, 2017).

Environment regulations: Environmental regulations are rules and requirements that generally cover pollution control and conservation management (U.S. Environmental Regulations, n.d.).

Corrosion resistance: "how well a substance (especially a metal) can withstand damage caused by oxidization or other chemical reactions" (corrosion resistance, n.d.).

Sustainability: "the quality of not being harmful to the environment or depleting natural resources, and thereby supporting long-term ecological balance" (Dictionary.com, n.d.).

Mechanical properties testing: "A mechanical test shows whether a material or part is suitable for its intended application by measuring properties such as elasticity, tensile strength, elongation, hardness, fracture toughness, impact resistance, stress rupture and the fatigue limit" (Element, n.d.).

Tech-gym facility: An engineering gym that is located at Wintec's Rotokauri Campus.

Noble metals: Materials that are less affected by the corrosion phenomena, as well as due to being the only elements that can be found in nature in their pure form (Bell , 2017).

Electrochemical potential: "A measure of the energy of the outer most electrons" (Electrochemical Potential, n.d.).

Plastic deformation: "A permanent deformation or change in shape of a solid body without fracture under the action of a sustained force" (plastic deformation, n.d.).

Elastic modulus: "Ratio of pressure (stress) applied to a body to the resistance (strain) produced by the body" (Elastic modulus, n.d.).

Abbreviations

ER-2: A developed version of ER-1 vessel, which is going to be produced by Earthrace Conservation Company.

Cp-Ti: Commercially pure titanium.

CPC: Carbon fibre composites.

UTS: Ultimate tensile strength, or ultimate tensile stress.

YS: Yield stress.

ISO: International Standards.

IMO: the International Maritime Organisation IMO.

Appendices

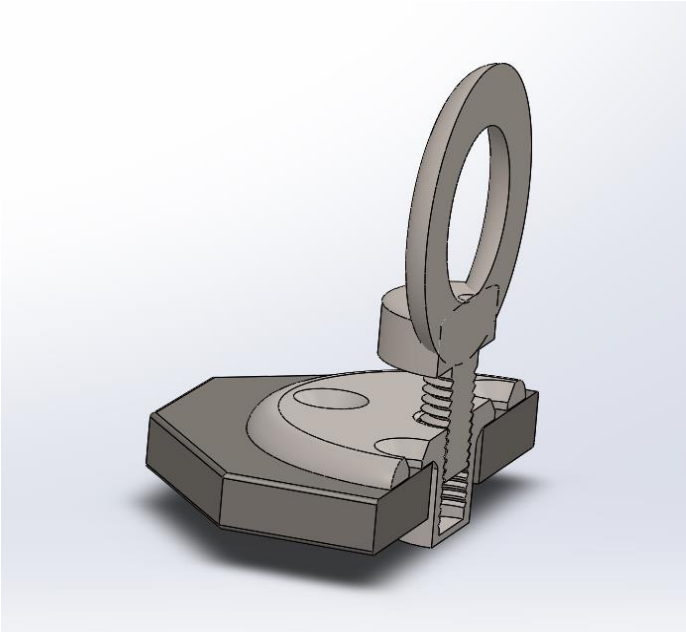

Figure 11: Required components for threading processes

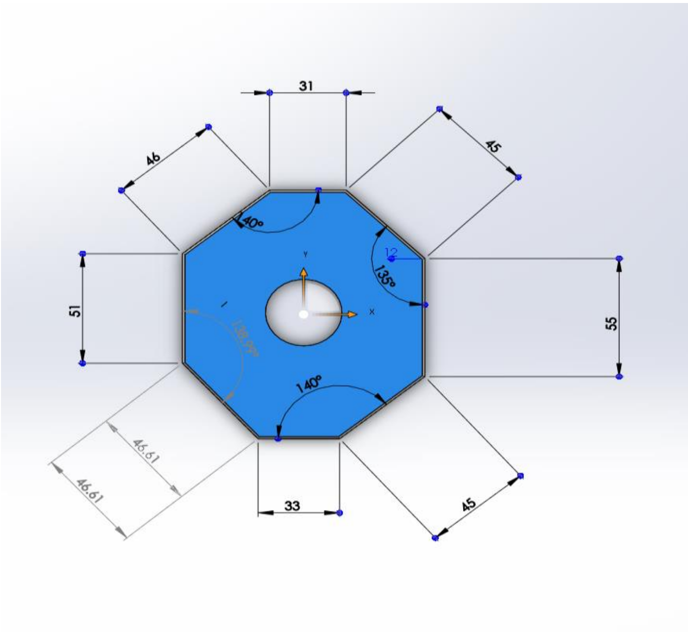

Figure 12: Dimensions for the steel holder

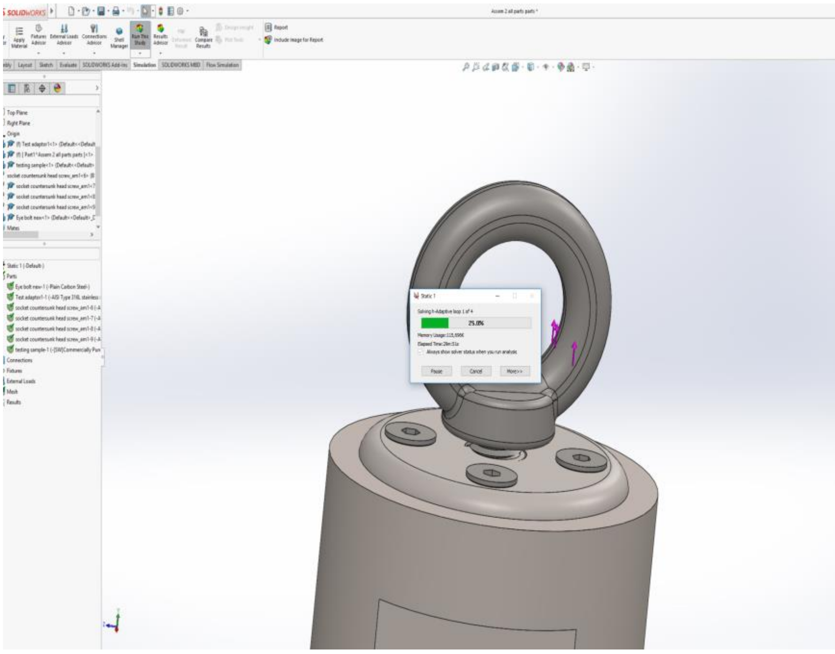

Figure 13: Issue occurred during the simulated test

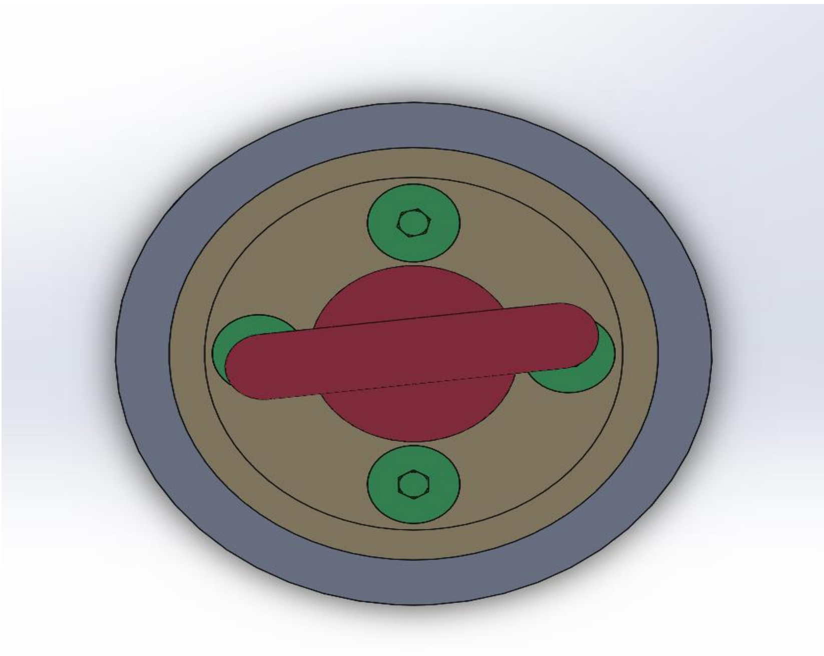

Figure 14: Top view of the drawn components

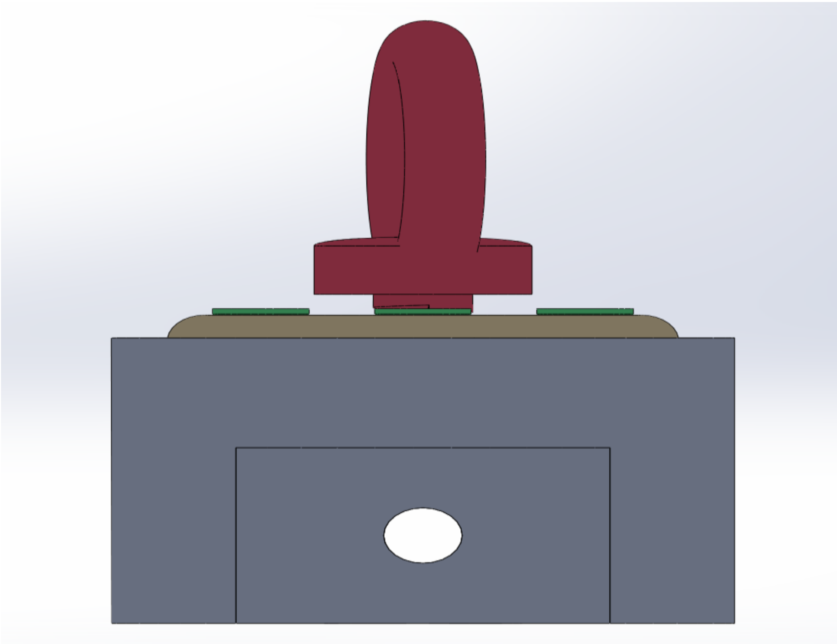

Figure 15: Side view of the drawn components

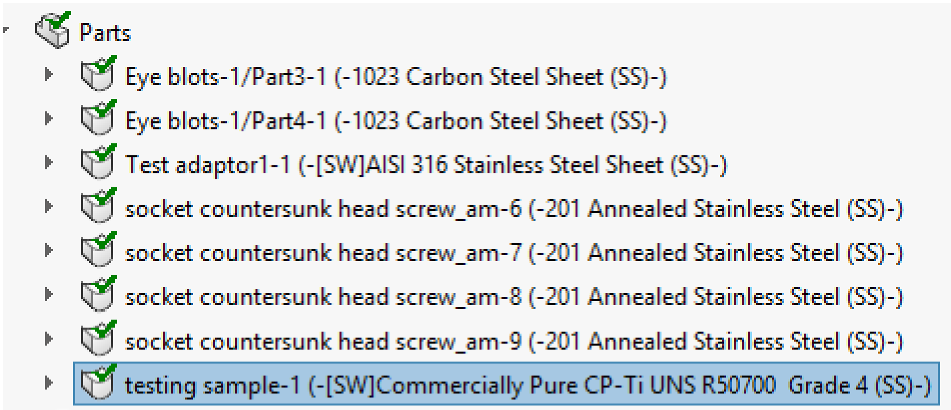

Figure 16: Specifications of the components in the Solidworks

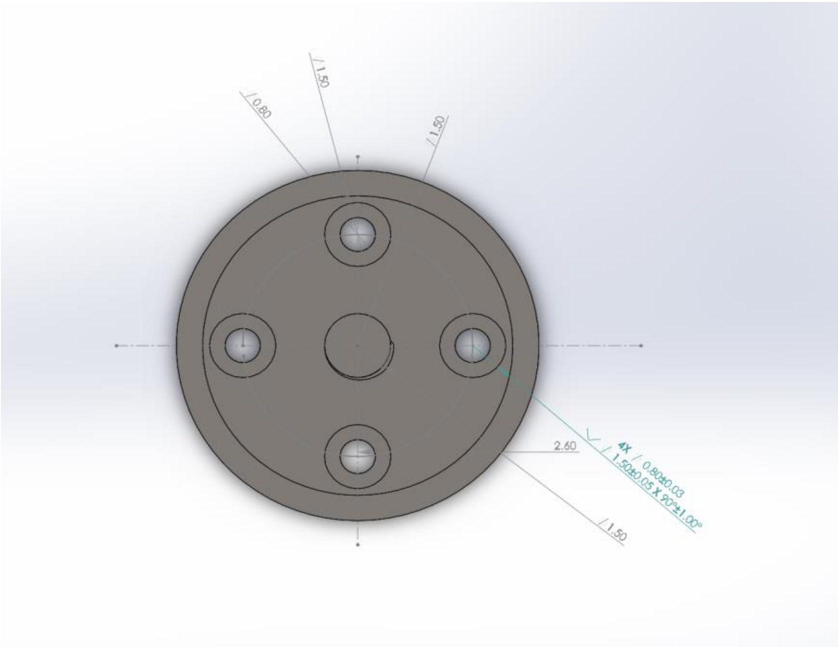

Figure 17: Dimensions of the titanium sample

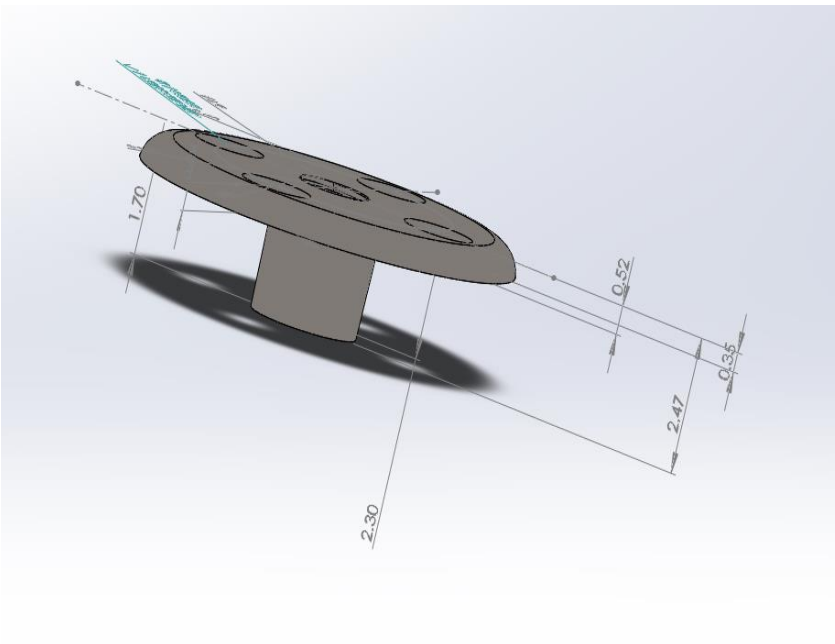

Figure 18: Dimensions of the titanium sample

Student’s Declaration

I have not copied any part of this report from any other person’s work, except as correctly referenced, as well as no other person has written any part in this report for me.

Mohammed Alqahtani
Student ID: 14399071

November 19, 2017

Completion date:

November 19, 2017